Chapter 8
PCBs/trans-Nonachlor in Fish

8.1 Results

Lake Michigan fish were collected from April 1994 through November 1995 for PCB and *trans*-nonachlor analysis. Forage fish species (alewife, bloater chub, deepwater sculpin, slimy sculpin, and rainbow smelt) and piscivorous fish species (lake trout and coho salmon) were collected and analyzed. Alewife and bloater chub were collected in two distinct size classes, and coho salmon were collected in three distinct age classes. Overall, a total of 796 fish samples were collected for the analysis of PCBs and *trans*-nonachlor (Table 8-1). Each sample was a composite of up to five fish of the same species and size or age category. With the exception of coho salmon, fish were collected from the following three biological sampling areas or biota boxes:

- **Sturgeon Bay biota box** – a series of three nearshore stations on the western side of the northern Lake Michigan basin near Sturgeon Bay, Wisconsin
- **Port Washington biota box** – a series of two mid-lake reef stations in the central Lake Michigan basin near Port Washington, Wisconsin
- **Saugatuck biota box** – a series of three nearshore stations on the eastern side of the southern Lake Michigan basin near Saugatuck, Michigan.

Coho salmon were collected from various sites selected to follow the seasonal migration of coho, which travel up Lake Michigan tributaries in the fall to spawn. During the summer, coho salmon were collected from the east central and west central regions of the lake. During the fall, coho salmon were collected from the northeastern side of the lake near the Platte River and on the western side of the lake near the Kewaunee River.

As noted in Chapter 2, there are 209 possible PCB congeners, and the investigators in this study reported results for 65 to 110 of these congeners, depending on the capabilities of each laboratory. The USGS laboratory determined results for 80 congeners or co-eluting congeners.

For the purposes of this report, we are presenting summaries of the results for the following subset of all of the analytes:

- PCB congener 33
- PCB congener 118
- PCB congener 180
- Total PCBs
- *trans*-nonachlor

Table 8-1. Number of Fish Samples Analyzed for PCB Congeners and *trans*-Nonachlor

Species/Size Category	Sampling Dates	Number of Samples Analyzed for PCBs and *trans*-Nonachlor
Alewife<120mm	05/18/94 to 10/12/95	60
Alewife>120mm	05/18/94 to 10/12/95	70
Bloater<160mm	05/18/94 to 10/13/95	70
Bloater>160mm	05/18/94 to 10/13/95	67
Coho-Adult	05/10/94 to 11/06/95	54
Coho-Hatchery	04/21/94 to 04/27/94	5
Coho-Yearling	10/18/94 to 11/16/94	8
Deepwater Sculpin	05/18/94 to 10/13/95	74
Lake Trout	05/12/94 to 10/26/95	246
Smelt	05/18/94 to 10/12/95	73
Slimy Sculpin	05/18/94 to 10/26/95	69
	Total	796

8.1.1 Species Variation

Tables 8-2 and 8-3 show the mean concentrations (on a wet-weight basis) of PCB 33, PCB 118, PCB 180, total PCBs, and *trans*-nonachlor in various Lake Michigan fish species. PCB and *trans*-nonachlor concentrations differed significantly among species (Figure 8-1). Significantly higher levels of total PCBs and *trans*-nonachlor were observed in Lake trout, a top predator in the Lake Michigan pelagic food web, than in any other fish species. Mean concentrations of PCB 33, PCB 118, PCB 180, total PCBs, and *trans*-nonachlor in lake trout were 1.4, 3.3, 3.4, 3.6, and 2.9 times higher than for any other species. This trend was similar for dry-weight basis PCB and *trans*-nonachlor concentrations (Table 8-4). Mean dry-weight basis total PCB concentrations in lake trout were from 1.2 to 16 times higher than in other species, and mean dry-weight basis *trans*-nonachlor concentrations were 2.4 to 34 times higher in lake trout than in other species.

When PCB and *trans*-nonachlor concentrations were compared among fish species on a lipid-normalized basis, lake trout still contained higher levels of contamination than all other species with the exception of adult coho salmon. Mean lipid-normalized total PCB and *trans*-nonachlor concentrations were highest in adult coho salmon and second highest in lake trout. Lipid-normalized total PCB and *trans*-nonachlor concentrations in these two top predator fish species were significantly higher than in any of the forage fish species (Figure 8-2 and Table 8-5). The higher mean concentrations of lipid-normalized contaminants in adult coho salmon were due to the relatively low lipid content in this species. Lipid content in adult coho salmon averaged only 4% compared to 16% in lake trout. Of the species analyzed in this study, only smelt contained lower lipid content (3.6%) than adult coho salmon.

The lowest total PCB and *trans*-nonachlor concentrations on a wet-weight, dry-weight, or lipid-weight basis were consistently found in hatchery and yearling coho salmon. This species is raised in hatcheries and annually stocked in Lake Michigan. Hatchery samples consisted of immature coho collected directly from the Platte River hatchery, and yearling samples consisted of immature coho collected in Lake Michigan. The reduced contamination in these sample types most likely reflects both the young age of the fish and reduced contaminant exposure from hatchery food and water sources.

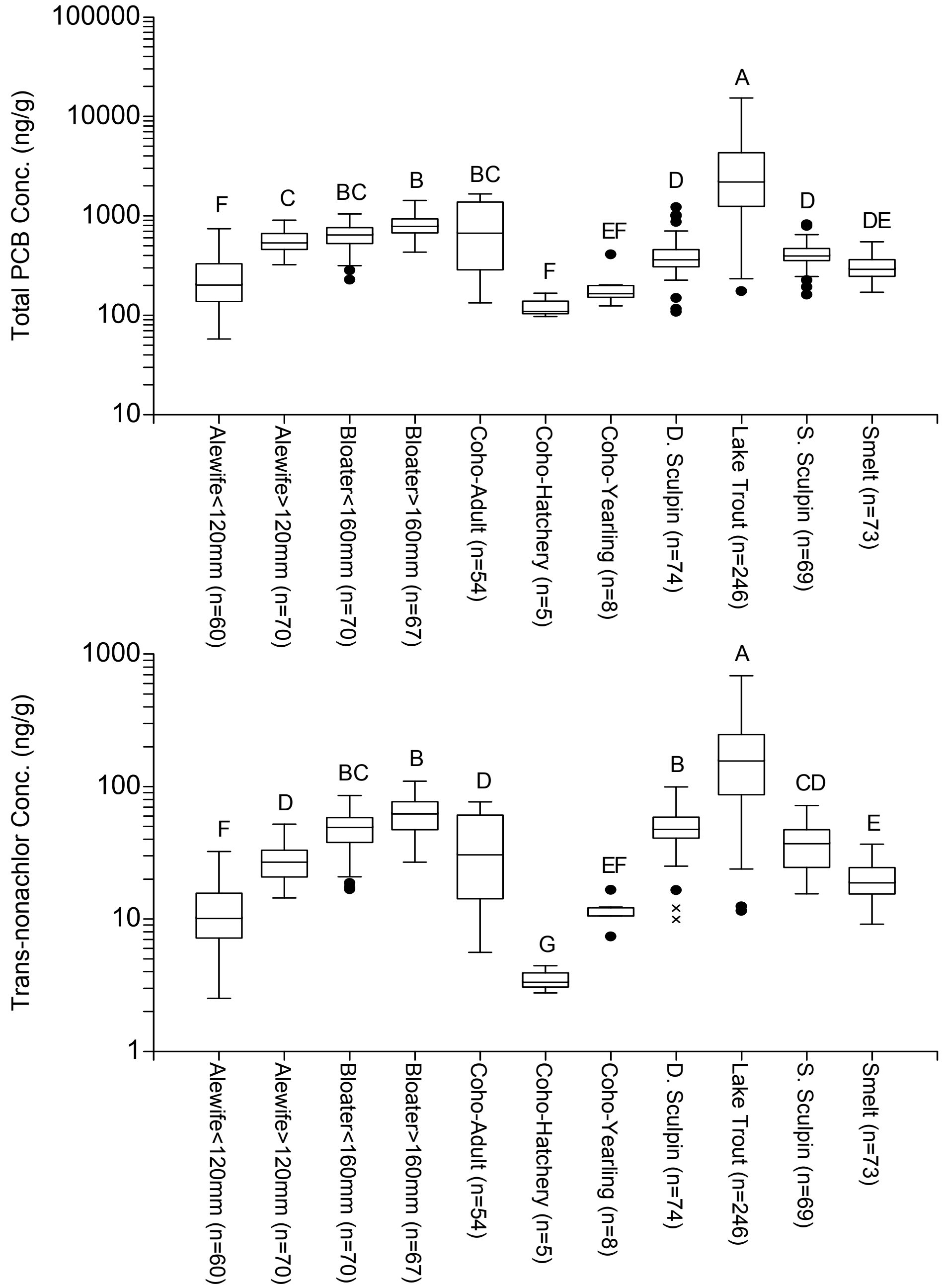
Table 8-2. Mean Concentrations of Specific PCB Congeners in Lake Michigan Fish (Wet-weight Basis)

Congener	Species/Size Category	N	Mean (ng/g)	Range (ng/g)	SD (ng/g)	RSD (%)	Below DL (%)
PCB 33	Alewife<120mm	60	8.3	0.0 to 49	9.6	120	45
	Alewife>120mm	70	23	0.0 to 83	17	75	13
	Bloater<160mm	69	3.9	0.0 to 36	9.5	240	84
	Bloater>160mm	67	4.0	0.0 to 36	9.5	240	82
	Coho-Adult	54	19	0.0 to 65	20	110	37
	Coho-Hatchery	5	0.0	0.0 to 0.0	0.0	-	100
	Coho-Yearling	8	0.0	0.0 to 0.0	0.0	-	100
	Deepwater Sculpin	74	0.16	0.0 to 7.4	1.0	620	97
	Lake Trout	246	33	0.0 to 230	50	150	50
	Smelt	72	1.7	0.0 to 18	4.1	240	83
	Slimy Sculpin	68	2.0	0.0 to 19	4.5	230	82
PCB 118	Alewife<120mm	60	8.3	1.4 to 23	4.9	59	0
	Alewife>120mm	70	23	12 to 34	5.2	22	0
	Bloater<160mm	70	28	8.2 to 56	9.9	35	0
	Bloater>160mm	67	39	16 to 76	12	32	0
	Coho-Adult	54	36	5.7 to 82	24	68	0
	Coho-Hatchery	5	6.5	5.4 to 8.7	1.3	21	0
	Coho-Yearling	8	7.7	4.5 to 19	4.8	62	0
	Deepwater Sculpin	74	34	4.1 to 110	21	61	0
	Lake Trout	246	130	4.2 to 790	100	77	0
	Smelt	73	16	7.9 to 28	4.8	31	0
	Slimy Sculpin	69	22	0 to 42	8.7	40	1.4
PCB180	Alewife<120mm	59	5.6	1.1 to 12	2.9	53	0
	Alewife>120mm	70	15	7.7 to 25	3.4	23	0
	Bloater<160mm	70	25	7.8 to 45	8.6	35	0
	Bloater>160mm	67	29	15 to 63	9.1	32	0
	Coho-Adult	54	25	4.2 to 50	16	65	0
	Coho-Hatchery	5	2.4	2.0 to 3.5	0.62	26	0
	Coho-Yearling	8	7.7	5.4 to 16	3.5	45	0
	Deepwater Sculpin	74	29	5.9 to 83	15	51	0
	Lake Trout	246	100	8.2 to 490	80	78	0
	Smelt	73	9.0	4.3 to 14	2.8	31	0
	Slimy Sculpin	69	19	7.2 to 52	7.2	39	0

Table 8-3. Mean Concentrations of Total PCBs and *trans*-Nonachlor in Lake Michigan Fish (Wet-weight Basis)

Analyte	Species/Size Category	N	Mean (ng/g)	Range (ng/g)	SD (ng/g)	RSD (%)	Below DL (%)
Total PCBs	Alewife<120mm	60	250	58 to 750	150	60	0
	Alewife>120mm	70	580	320 to 910	140	24	0
	Bloater<160mm	70	650	230 to 1000	180	28	0
	Bloater>160mm	67	830	430 to 1400	210	25	0
	Coho-Adult	54	810	130 to 1700	520	64	0
	Coho-Hatchery	5	120	97 to 170	27	22	0
	Coho-Yearling	8	200	120 to 400	90	46	0
	Deepwater Sculpin	74	420	110 to 1200	200	48	0
	Lake Trout	246	3000	180 to 15000	2300	76	0
	Smelt	73	310	170 to 550	83	27	0
	Slimy Sculpin	69	430	160 to 820	130	30	0
trans-Nonachlor	Alewife<120mm	60	12	2.5 to 32	7.3	59	0
	Alewife>120mm	70	28	14 to 52	9.0	32	0
	Bloater<160mm	70	48	17 to 85	15	31	0
	Bloater>160mm	67	63	27 to 110	19	30	0
	Coho-Adult	54	38	5.6 to 76	25	65	0
	Coho-Hatchery	5	3.5	2.8 to 4.4	0.60	17	0
	Coho-Yearling	8	11	7.4 to 17	2.6	23	0
	Deepwater Sculpin	74	50	9.9 to 99	17	34	0
	Lake Trout	246	180	12 to 680	120	65	0
	Smelt	73	20	9.1 to 37	6.0	30	0
	Slimy Sculpin	69	38	15 to 72	14	37	0

Figure 8-1. Total PCB and *trans*-Nonachlor Concentrations in Lake Michigan Fish (Wet-weight Basis)

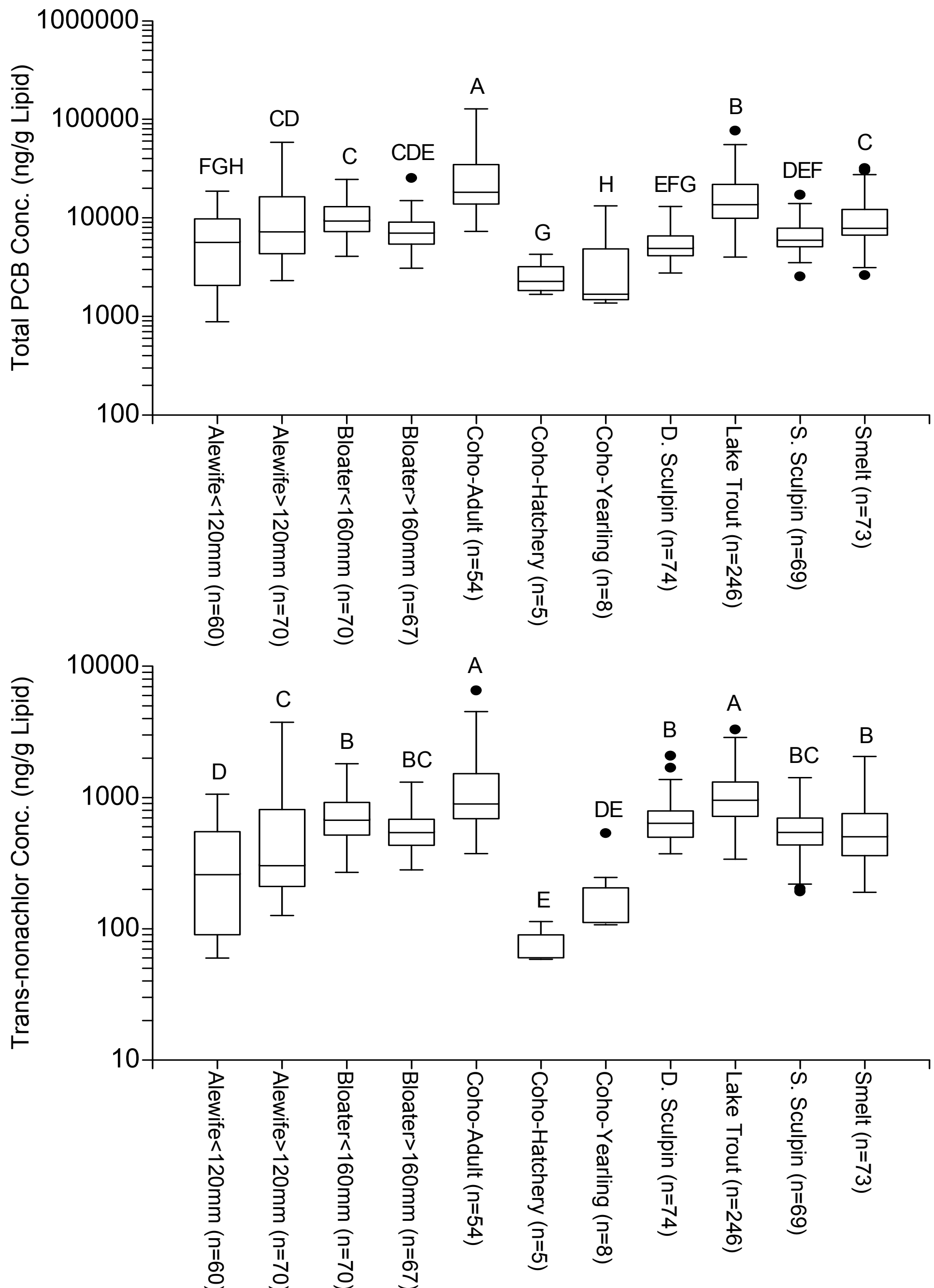


Boxes represent the 25th percentile (bottom of box), 50th percentile (center line), and 75th percentile (top of box) results. Bars represent the results nearest 1.5 times the inter-quartile range (IQR=75th-25th percentile) away from the nearest edge of the box. Circles represent results beyond 1.5*IQR from the box. The Xs represent results beyond 3*IQR from the box. The letters (A - G) above the boxes represent the results of the analysis of variance and multiple comparisons test. Boxes with the same letter were not statistically different (at alpha = 0.05). Concentration is plotted on a log scale.

Table 8-4. Mean Concentrations of Total PCBs and *trans*-Nonachlor in Lake Michigan Fish (Dry-weight Basis)

Analyte	Species/Size Category	N	Mean (ng/g)	Range (ng/g)	SD (ng/g)	RSD (%)	Below DL (%)
Total PCBs	Alewife<120mm	60	990	230 to 3000	580	58	0
	Alewife>120mm	70	2100	1100 to 3500	580	27	0
	Bloater<160mm	70	2500	930 to 4000	750	30	0
	Bloater>160mm	67	6700	1300 to 5000	760	28	0
	Coho-Adult	54	2900	570 to 6000	1700	59	0
	Coho-Hatchery	5	480	370 to 710	130	27	0
	Coho-Yearling	8	690	400 to 1700	410	60	0
	Deepwater Sculpin	74	1700	440 to 4100	650	40	0
	Lake Trout	246	7800	770 to 37000	5400	70	0
	Smelt	73	1400	660 to 2400	390	28	0
	Slimy Sculpin	69	1700	620 to 3600	530	32	0
trans-Nonachlor	Alewife<120mm	60	50	9.8 to 130	31	62	0
	Alewife>120mm	70	110	52 to 230	38	36	0
	Bloater<160mm	70	190	69 to 310	59	32	0
	Bloater>160mm	67	200	110 to 390	61	30	0
	Coho-Adult	54	140	24 to 300	82	60	0
	Coho-Hatchery	5	14	11 to 19	2.9	21	0
	Coho-Yearling	8	38	29 to 67	12	31	0
	Deepwater Sculpin	74	200	40 to 380	69	34	0
	Lake Trout	246	480	48 to 1700	280	58	0
	Smelt	73	87	40 to 170	28	32	0
	Slimy Sculpin	69	150	60 to 290	55	38	0

Figure 8-2. Total PCB and *trans*-Nonachlor Concentrations in Lake Michigan Fish (Lipid-weight Basis)



Boxes represent the 25th percentile (bottom of box), 50th percentile (center line), and 75th percentile (top of box) results. Bars represent the results nearest 1.5 times the inter-quartile range (IQR=75th-25th percentile) away from the nearest edge of the box. Circles represent results beyond 1.5*IQR from the box. The letters (A - H) above the boxes represent the results of the analysis of variance and multiple comparisons test. Boxes with the same letter were not statistically different (at alpha = 0.05). Concentration is plotted on a log scale.

Table 8-5. Mean Concentrations of Total PCBs and *trans*-Nonachlor in Lake Michigan Fish (Lipid-weight Basis)

Analyte	Species/Size Category	N	Mean (ng/g)	Range (ng/g)	SD (ng/g)	RSD (%)	Below DL (%)
Total PCBs	Alewife<120mm	60	6800	880 to 19000	5200	76	0
	Alewife>120mm	70	12000	2300 to 59000	12000	98	0
	Bloater<160mm	70	10000	4100 to 25000	4100	40	0
	Bloater>160mm	67	7900	3100 to 25000	3700	46	0
	Coho-Adult	54	27000	7300 to 130000	22000	82	0
	Coho-Hatchery	5	2500	1700 to 4300	1000	40	0
	Coho-Yearling	8	3700	1400 to 13000	4300	120	0
	Deepwater Sculpin	74	5700	2800 to 13000	2300	40	0
	Lake Trout	246	17000	4000 to 77000	9800	57	0
	Smelt	73	11000	2600 to 32000	6700	64	0
	Slimy Sculpin	69	6800	3000 to 17000	2700	39	0
trans-Nonachlor	Alewife<120mm	60	350	60 to 1100	290	82	0
	Alewife>120mm	70	630	130 to 3700	680	110	0
	Bloater<160mm	70	760	270 to 1800	320	42	0
	Bloater>160mm	67	580	280 to 1300	200	35	0
	Coho-Adult	54	1200	370 to 6500	1000	84	0
	Coho-Hatchery	5	73	59 to 110	23	32	0
	Coho-Yearling	8	180	110 to 530	150	83	0
	Deepwater Sculpin	74	710	370 to 2100	290	41	0
	Lake Trout	246	1100	340 to 3300	490	45	0
	Smelt	73	670	190 to 2000	440	65	0
	Slimy Sculpin	69	600	190 to 1400	240	41	0

8.1.2 Factors Affecting Contaminant Concentrations

In general, log-transformed total PCB and *trans*-nonachlor concentrations were highly correlated with both lipid content and fish length (Table 8-6). For smelt and slimy sculpin, these correlations were not significant (at the 95% confidence level) or were weak, and correlations with lipid content were weak in alewife. For all other species, however, correlations were highly significant ($p<0.0001$) and r^2 values ranged from 0.27 to 0.89 for correlations between fish contaminant concentration and length and from 0.10 to 0.69 for correlations between fish contaminant concentration and lipid content. It should be noted that analyzed fish samples were composites of up to five individual fish. Correlations with fish length reflect the midpoint of the range of fish lengths that were incorporated into the composite sample. It is likely that correlations between contaminant concentrations and fish length would be stronger had contaminant concentrations been measured in individual fish samples to allow for direct comparison of length and contaminant concentration.

Multiple regression analysis was conducted to partition the effects of length and lipid content on fish contamination (Table 8-7). Contaminant concentrations (log-transformed total PCB and log-transformed *trans*-nonachlor) in alewife and lake trout were significantly affected only by length and not by lipid content. Lipid content remained correlated with contaminant concentrations (Table 8-6) through its correlation with fish length, but in a multiple regression model, only length significantly accounted for variability in alewife and lake trout contaminant concentrations. *trans*-Nonachlor concentrations in smelt also were only affected by length, and not lipid content. In slimy sculpin, contaminant concentrations (both PCB and *trans*-nonachlor) were significantly affected only by lipid content and not by fish length (Table 8-7). For the remaining fish species, both length and lipid content or an interaction of the two parameters significantly affected fish contaminant concentrations.

Table 8-6. Correlation Between Log-transformed Total PCBs and *trans*-Nonachlor Concentrations in Lake Michigan Fish and Fish Length and Lipid Content

Analyte	Species/Size Category	Fish Length			Lipid Content		
		Correlation Coefficient	p	r^2	Correlation Coefficient	p	r^2
Total PCBs	Alewife	0.78	<0.0001	0.61	0.25	0.0042	0.062
	Bloater	0.54	<0.0001	0.29	0.31	<0.0001	0.10
	Coho-Adult	0.84	<0.0001	0.70	0.73	<0.0001	0.53
	Deepwater Sculpin	0.56	<0.0001	0.32	0.62	<0.0001	0.39
	Lake Trout	0.94	<0.0001	0.89	0.83	<0.0001	0.69
	Smelt	0.40	0.0004	0.16	-0.34	0.0035	0.11
	Slimy Sculpin	0.14	0.25	0.020	0.32	0.017	0.10
trans-Nonachlor	Alewife	0.80	<0.0001	0.63	0.25	0.0042	0.062
	Bloater	0.52	<0.0001	0.27	0.47	<0.0001	0.22
	Coho-Adult	0.82	<0.0001	0.66	0.74	<0.0001	0.55
	Deepwater Sculpin	0.72	<0.0001	0.52	0.57	<0.0001	0.32
	Lake Trout	0.91	<0.0001	0.82	0.82	<0.0001	0.67
	Smelt	0.27	0.021	0.07	-0.20	0.098	0.038
	Slimy Sculpin	0.055	0.65	0.0031	0.311	0.020	0.10

Contaminant concentrations generally increased with increasing lipid content and with increasing fish length. Hydrophobic organic contaminants such as PCBs and *trans*-nonachlor preferentially concentrate in the fatty tissues of organisms, so those organisms with higher lipid content are expected to contain more of these contaminants. Older fish also are likely to accumulate higher levels of contaminants because they have experienced longer exposure durations to environmental contaminants. As a surrogate of fish age, fish length is similarly correlated with fish contaminant concentrations. Contaminant concentrations generally increased exponentially with increasing fish length, producing a linear relationship between fish length and log concentration. Figure 8-3 shows the relationship between fish length and contaminant concentrations in lake trout. The length of lake trout accounted for 89% (r^2 = 0.89) of the variability in total PCB concentrations and 82% (r^2 = 0.82) of the variability in *trans*-nonachlor concentrations. Significant relationships between fish length and contaminant concentrations, such as the one depicted in Figure 8-3 for lake trout, can be useful in setting and evaluating size-based fish advisory levels.

Figure 8-3. Relationship between Fish Length and Total PCB and *trans*-Nonachlor Concentrations in Lake Michigan Lake Trout

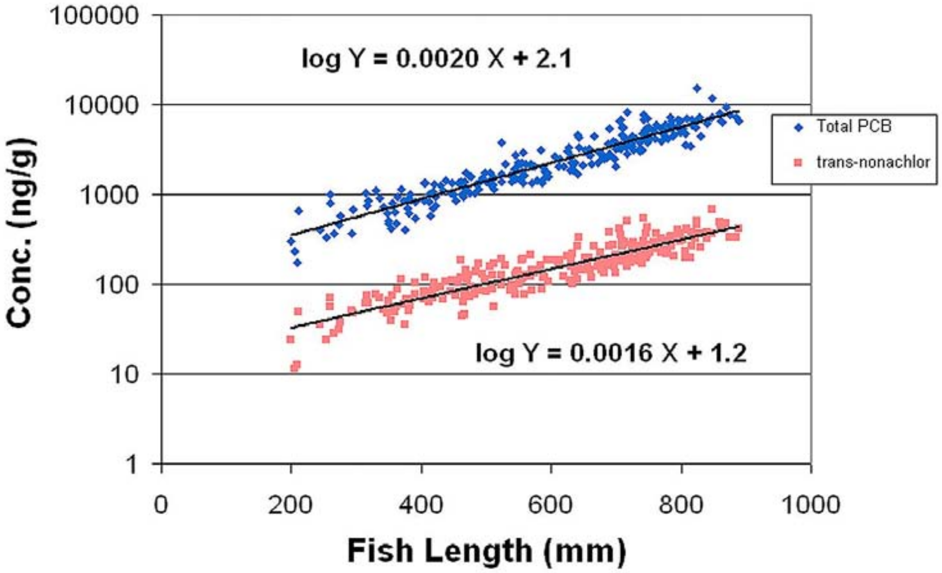


Table 8-7. Results of Multiple Regression Significance Test for Effects of Fish Length and Lipid Content on Concentrations of Total PCBs and *trans*-Nonachlor Concentrations in Lake Michigan Fish

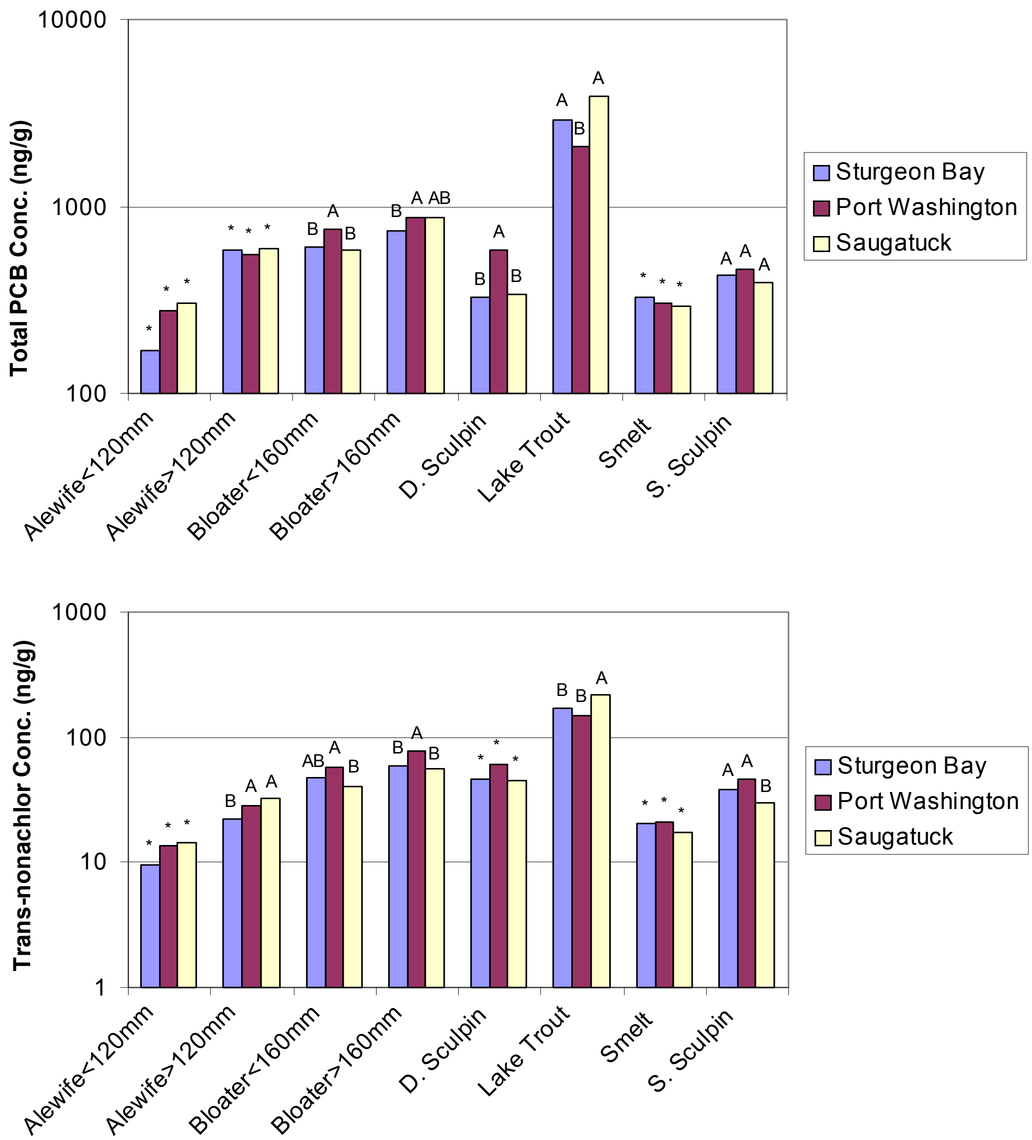
Analyte	Species/Size Category	p-value		
		Fish Length	Lipid Content	Interaction[a]
Total PCBs[c]	Alewife	<0.0001	0.43	NS
	Bloater	<0.0001[b]	0.014[b]	0.0058
	Coho-Adult	<0.0001[b]	0.0002[b]	0.0033
	Deepwater Sculpin	0.0014	0.0001	NS
	Lake Trout	<0.0001	0.33	NS
	Smelt	0.0019	0.016	NS
	Slimy Sculpin	0.080	0.011	NS
trans-Nonachlor[c]	Alewife	<0.0001	0.35	NS
	Bloater	0.0004	0.036	NS
	Coho-Adult	<0.0001[b]	<0.0001[b]	0.0006
	Deepwater Sculpin	<0.0001[b]	0.0043[b]	0.015
	Lake Trout	<0.0001	0.45	NS
	Smelt	0.042	0.21	NS
	Slimy Sculpin	0.31	0.014	NS

[a] NS indicates that the interaction term was not significant and was removed from the model.
[b] Due to the significant interaction term, interpretation of the effect of this variable on PCB and *trans*-nonachlor concentrations is confounded by the remaining variable.
[c] Total PCB and *trans*-nonachlor concentrations were log transformed.

8.1.3 Geographical Variation

With the exception of coho salmon, fish were collected from three biological sampling areas or biota boxes (Saugatuck, Sturgeon Bay, and Port Washington) during the spring, summer, and autumn months. Mean total PCB and *trans*-nonachlor concentrations in alewife and lake trout were highest at the Saugatuck biota box, and concentrations in bloater chub, deepwater sculpin, and slimy sculpin were highest at the Port Washington biota box (Figure 8-4). Total PCB concentrations in smelt were highest at Sturgeon Bay, and *trans*-nonachlor concentrations in smelt were highest at Port Washington. For a given species, mean contaminant concentrations differed by 6 to 46% among sampling stations.

Figure 8-4. Total PCB and *trans*-Nonachlor Concentrations in Fish from Three Biological Sampling Stations in Lake Michigan



Bars with the same letter were not statistically different (at alpha = 0.05). Bars with an asterisk indicate that there was significant interaction between the effects of station and season.

Two-way analysis of variance (accounting for sampling station and season) revealed that for some species, differences in contaminant concentrations among sampling stations were statistically significant. Geographical trends in total PCB contamination, however, were species specific, with some species containing higher contamination at Port Washington and other species containing higher contamination at Saugatuck (Figure 8-4). Deepwater sculpin and small bloater chub from Port Washington contained significantly higher levels of PCBs than the same species collected at Sturgeon Bay or Saugatuck, and large bloater chub from Port Washington contained significantly higher levels of PCBs than the same species collected at Sturgeon Bay. This trend was reversed, however, in lake trout. Lake trout from Port Washington contained significantly lower levels of PCBs than lake trout from Sturgeon Bay or Saugatuck. There were no significant differences among sites in slimy sculpin contamination. For the remaining species, there was significant interaction between the effects of station and season, meaning that significant differences between stations were only observed during given seasons. In the spring, small alewife from Sturgeon Bay were significantly lower in PCBs than alewife from Port Washington or Saugatuck. In spring, smelt from Sturgeon Bay contained significantly less PCBs than smelt from Port Washington. In autumn, Port Washington smelt were significantly lower in PCBs than Sturgeon Bay or Saugatuck smelt.

Total PCBs measured in the LMMB Study were highest in lake trout from Saugatuck, and lowest in lake trout from Port Washington. This geographical pattern of PCB contamination in Lake Michigan lake trout was previously reported by Madenjian *et al.* (1999a) and also observed by Miller *et al.* (1992). Miller *et al.* (1992) found that lake trout at deep water reef locations, such as Port Washington, contained lower PCB contamination than lake trout collected from nearshore locations, such as Saugatuck and Sturgeon Bay. Using LMMB Study data, Madenjian *et al.* (1999a) identified significantly higher concentrations of PCBs in lake trout from Saugatuck than from Sturgeon Bay or Port Washington and significantly higher concentrations of PCBs in lake trout from Sturgeon Bay than from Port Washington. Madenjian *et al.* (1999a) explained that these differences in PCB fish contamination levels among various sites were likely due to differences in organism size or differences in lake trout diet at the sites. Lower concentrations in lake trout from Port Washington were explained by the fact that the fish from this site were smaller than fish from the other two sites. Lower concentrations at Sturgeon Bay than at Saugatuck were explained by a lake trout diet that consisted of a higher proportion of more contaminated prey species at Saugatuck than at Sturgeon Bay. Based on analyses of guts contents, Madenjian *et al.* (1999a) determined that at Saugatuck, lake trout diet consisted of 55% alewife, 35% bloater, and 10% sculpins and rainbow smelt. This diet contained a combined 0.64 mg/kg PCBs, compared to a 80% alewife and 20% rainbow smelt diet at Sturgeon Bay that contained a combined 0.53 mg/kg PCBs.

Similar to total PCB contamination, geographical trends in *trans*-nonachlor contamination were species specific (Figure 8-4). Large alewife, bloater chub, and slimy sculpin from Port Washington contained significantly higher *trans*-nonachlor concentrations than the same species at one or more other stations. Large alewife and lake trout from Saugatuck contained significantly higher *trans*-nonachlor concentrations than the same species at one or more other stations. Only slimy sculpin contained significantly higher *trans*-nonachlor concentrations at Sturgeon Bay than other stations. For small alewife, deepwater sculpin, and smelt, there was significant interaction between the effects of station and season. *trans*-Nonachlor contamination in small alewife was significantly higher at Port Washington and Saugatuck than at Sturgeon Bay during the spring, higher at Sturgeon Bay than Saugatuck during the summer, and higher at Port Washington than Sturgeon Bay during autumn. In deepwater sculpin, *trans*-nonachlor contamination was higher at Port Washington than Saugatuck during the summer. In smelt, *trans*-nonachlor contamination was significantly higher at Sturgeon Bay than at Port Washington during the spring and higher at Port Washington than Sturgeon Bay or Saugatuck during autumn.

In summary, differences in fish contamination levels among sites were relatively small (6% to 46%) compared to species differences, which varied by more than a factor of 12, or differences attributed to fish size or lipid content, where contaminant levels varied over an order of magnitude (Figure 8-3). Significant differences in fish contamination levels among sites were species specific. Some species showed significantly higher contamination levels at Saugatuck, and other species showed significantly higher contamination levels at Port Washington. In general, fish contamination levels at Sturgeon Bay were lower than at the remaining sites. Differences in fish contamination levels among sites could be due to increased water, sediment, and food contamination levels at specific sites. Contours of water and sediment PCB levels did show increased concentrations (see Chapters 5 and 6) on the eastern shore of the southern basin (near Saugatuck) and in the center of the southern basin (near Port Washington biota box). PCB concentrations in the lower pelagic food web also were generally higher at Saugatuck (see Chapter 7). Differences in fish contamination levels also could be due to differences in fish size or lipid content at the various sites, or as Madenjian *et al.* (1999a) suggested, differences in fish diets among the various sites.

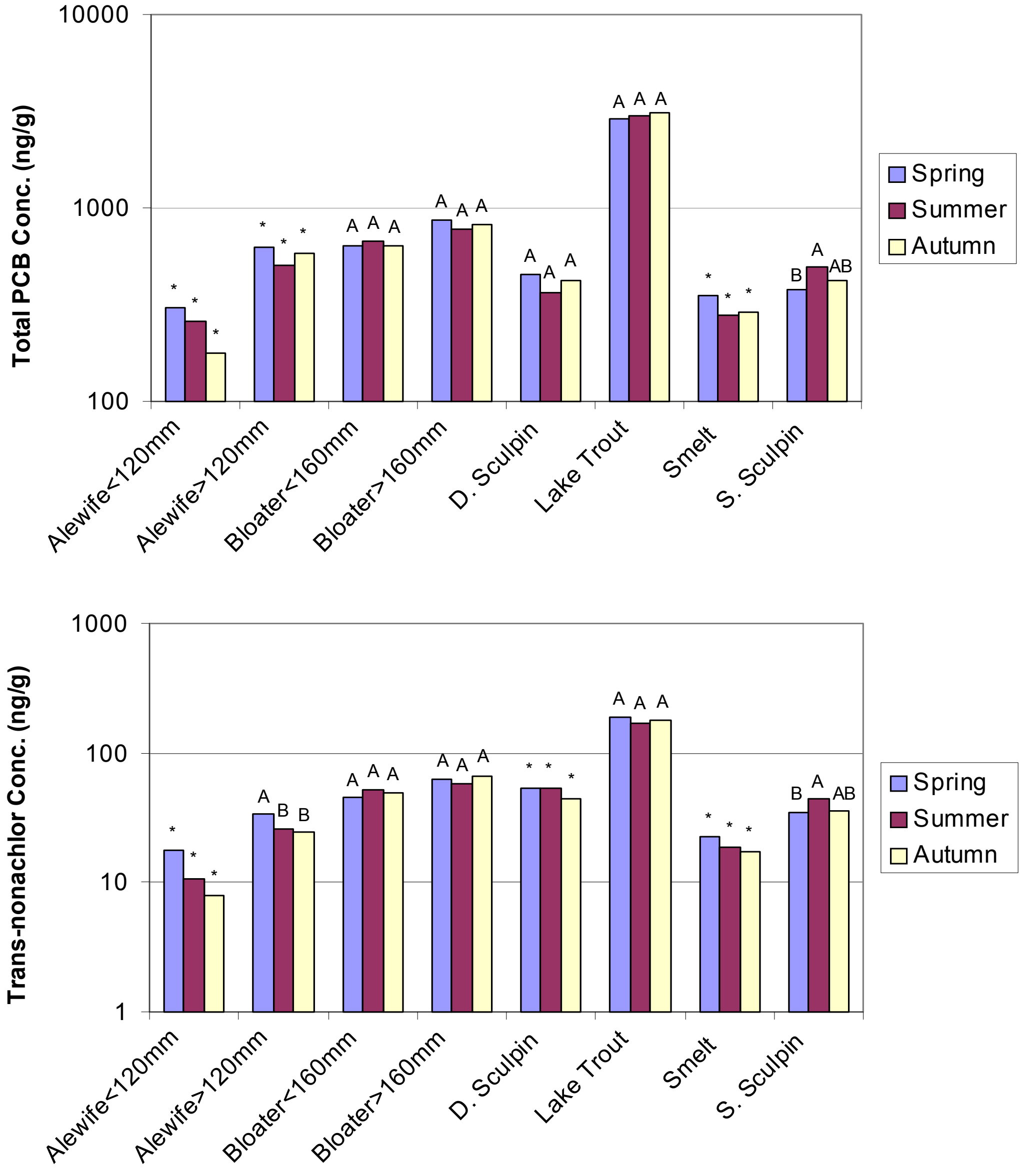
8.1.4 Seasonal Variation

Two-way analysis of variance (accounting for sampling station and season) revealed few significant differences in contaminant concentrations among the three sampling seasons (spring, summer, and autumn). No significant differences among season were observed for bloater chub, deepwater sculpin, and lake trout total PCB concentrations. Total PCB concentrations in slimy sculpin were significantly higher in summer than in spring. For alewife and smelt, there was significant interaction between the effects of season and station. At Sturgeon Bay, small alewife contained significantly higher PCB concentrations during the summer than during autumn, and smelt contained significantly higher PCB concentrations during spring and summer than during autumn. At Port Washington, large alewife contained significantly higher PCB concentrations during spring than during summer. At Saugatuck, small alewife and smelt contained significantly higher PCB concentrations during spring than in summer or autumn.

For *trans*-nonachlor, significant differences in contaminant concentrations among the three sampling seasons were observed for some species but not for others. *trans*-Nonachlor concentrations in bloater chub and lake trout did not differ significantly between seasons. Large alewife contained significantly higher *trans*-nonachlor concentrations in spring than in summer or autumn, and slimy sculpin contained significantly higher *trans*-nonachlor concentrations in summer than in spring. For small alewife, deepwater sculpin, and smelt, there was significant interaction between the effects of season and station. At Sturgeon Bay, small alewife, deepwater sculpin, and smelt contained significantly higher *trans*-nonachlor concentrations during the spring and summer than during autumn. At Port Washington, small alewife contained significantly higher *trans*-nonachlor concentrations during spring than during autumn, and deepwater sculpin contained significantly higher *trans*-nonachlor concentrations during summer than spring or autumn. At Saugatuck, small alewife contained significantly higher *trans*-nonachlor concentrations during spring than in summer or autumn, and smelt contained significantly higher *trans*-nonachlor concentrations during spring and summer than autumn.

In conclusion, most fish species did not show significant differences in fish contamination levels among seasons. Those significant differences that were observed also were relatively small in comparison to species differences and differences due to fish length or lipid content. As described for site variations, differences in fish contamination levels among seasons also could be due to differences in fish size or lipid content during the various seasons or differences in fish diet throughout the changing seasons.

Figure 8-5. Total PCB and *trans*-Nonachlor Concentrations in Lake Michigan Fish during Spring, Summer, and Autumn



Bars with the same letter were not statistically different (at alpha = 0.05). Bars with an asterisk indicate that there was significant interaction between the effects of station and season.

8.1.5 Bioaccumulation

Persistent organic pollutants, such as PCBs and *trans*-nonachlor, typically accumulate in living organisms above concentrations found in the water. This accumulation is due to the preferred partitioning of hydrophobic organic contaminants in organic tissues (such as lipids) over water, uptake from food, and/or reduced metabolism and elimination of persistent contaminants. The degree of accumulation is often quantified by a bioaccumulation factor, which is the ratio of the concentration of pollutant in an organism to the concentration of that pollutant in the water. When pollutants are increasingly accumulated with each trophic level of a food chain (or biomagnified), a biomagnification factor can be used to quantify the degree of accumulation from one trophic level to the next. A biomagnification factor is the ratio of the concentration of pollutant in organisms at a particular trophic level to the concentration of that pollutant in the next lowest trophic level.

To evaluate the degree of accumulation of PCBs and *trans*-nonachlor in fish species of Lake Michigan, bioaccumulation factors were calculated for each species (Table 8-8). Bioaccumulation factors were calculated as the mean dry-weight concentration in fish divided by the lake-wide mean concentration in Lake Michigan. Concentrations of total PCBs in fish were generally 10^6 to 10^7 times higher than dissolved concentrations of PCBs in Lake Michigan water, which averaged 0.18 ng/L (or 0.00018 ng/g). Bioaccumulation factors for total PCBs from water to fish ranged from 5.5×10^6 for small alewife (<120mm) to 4.3×10^7 for lake trout. Bioaccumulation factors were generally lower for the less-chlorinated PCB congeners and higher for the more-chlorinated congeners. Bioaccumulation factors for PCB 33 ranged from 6.8×10^4 to 9.4×10^6, while bioaccumulation factors for PCB 180 ranged from 4.7×10^7 to 5.6×10^8. *trans*-Nonachlor accumulation was of the same magnitude as total PCB accumulation in fish. Bioaccumulation factors for *trans*-nonachlor ranged from 8.7×10^6 to 8.3×10^7.

Table 8-8. Bioaccumulation Factors for PCBs and *trans*-Nonachlor in Lake Michigan Fish

Species/Size Category	Bioaccumulation Factor				
	PCB 33	PCB 118	PCB 180	Total PCBs	*trans*-Nonachlor
Alewife<120mm	3.8×10^6	1.4×10^7	4.7×10^7	5.5×10^6	8.7×10^6
Alewife>120mm	9.4×10^6	3.5×10^7	1.2×10^8	1.2×10^7	1.8×10^7
Bloater<160mm	1.8×10^6	4.4×10^7	2.0×10^8	1.4×10^7	3.2×10^7
Bloater>160mm	1.5×10^6	5.1×10^7	1.9×10^8	1.5×10^7	3.5×10^7
Coho-Adult	7.0×10^6	5.2×10^7	1.8×10^8	1.6×10^7	2.4×10^7
Deepwater Sculpin	6.8×10^4	5.5×10^7	2.4×10^8	9.1×10^6	3.5×10^7
Lake Trout	9.2×10^6	1.4×10^8	5.6×10^8	4.3×10^7	8.3×10^7
Smelt	7.9×10^5	2.8×10^7	8.2×10^7	7.5×10^6	1.5×10^7
Slimy Sculpin	8.8×10^5	3.5×10^7	1.5×10^8	9.1×10^6	2.5×10^7

To evaluate the accumulation and transfer of PCBs and *trans*-nonachlor between trophic levels within the upper pelagic food web, biomagnification factors were calculated. Biomagnification factors were calculated between forage fish species (alewife, bloater chub, sculpin, and smelt) and piscivorous fish species (lake trout and coho salmon). Total PCB biomagnification factors from forage fish to piscivorous fish were 1.6 and 4.2 for coho salmon and lake trout, respectively. *trans*-Nonachlor biomagnification factors from forage fish to piscivorous fish were 0.96 and 3.4 for coho salmon and lake trout, respectively. As evidenced by the biomagnification factor of less than one (<1) for coho salmon, *trans*-nonachlor was not biomagnified in the trophic transfer from forage fish to coho salmon.

8.2 Quality Implementation and Assessment

As described in Section 1.5.5, the LMMB QA program prescribed minimum standards to which all organizations collecting data were required to adhere. The quality activities implemented for the PCBs and *trans*-nonachlor monitoring portion of the study are further described in Section 2.7 and included use of SOPs, training of laboratory and field personnel, and establishment of MQOs for study data. A detailed description of the LMMB quality assurance program is provided in *The Lake Michigan Mass Balance Study Quality Assurance Report* (USEPA, 2001b). A brief summary of the quality of fish PCB and *trans*-nonachlor data is provided below.

Quality Assurance Project Plans (QAPPs) were developed by the PIs and were reviewed and approved by GLNPO. Each researcher trained field personnel in sample collection SOPs prior to the start of the field season and analytical personnel in analytical SOPs prior to sample analysis. Each researcher submitted test electronic data files containing field and analytical data according to the LMMB data reporting standard prior to study data submittal. GLNPO reviewed these test data sets for compliance with the data reporting standard and provided technical assistance to the researchers. In addition, each researcher's laboratory was audited during an on-site visit at least once during the time LMMB samples were being analyzed. The auditors reported positive assessments and did not identify issues that adversely affected the quality of the data.

As discussed in Section 2.7, data verification was performed by comparing all field and QC sample results produced by each PI with their MQOs and with overall LMMB Study objectives. Analytical results were flagged when pertinent QC sample results did not meet acceptance criteria as defined by the MQOs. These flags were not intended to suggest that data were not useable; rather they were intended to caution the user about an aspect of the data that did not meet the predefined criteria. Table 8-9 provides a summary of flags applied to the fish PCB and *trans*-nonachlor data. The summary includes the flags that directly relate to evaluation of the MQOs to illustrate some aspects of data quality, but does not include all flags applied to the data to document sampling and analytical information, as discussed in Section 2.7. Compared to other matrices, the percentage of results that were qualified for these criteria is relatively small. No results were qualified as invalid, thus all results are represented in the analysis of fish PCB and *trans*-nonachlor concentrations presented in this report.

PIs used surrogate spikes to monitor the bias of the analytical procedure. The PCB and *trans*-nonachlor results were corrected for the recoveries of the surrogates. Only 8 to 9% of PCB and *trans*-nonachlor results were qualified for surrogate recovery problems (Table 8-9). Each of these samples was flagged for surrogate recoveries that exceeded the upper MQO of 130% recovery. Laboratory matrix spike samples also were used to monitor analytical bias. Only 2% of PCB 118, PCB 180, and *trans*-nonachlor samples were flagged for associated failed laboratory matrix spikes that exceeded the upper MQO of 120% recovery. Performance check samples also were used to monitor analytical bias. For PCB 180, 5% of samples were flagged for associated failed performance check samples, and 20% of *trans*-nonachlor samples were flagged for associated failed performance check samples. Based on an analysis of matrix spikes, standard reference material recovery, blank contamination, and other internal QC data, no samples were qualified by the PI and QC coordinators as high or low biased.

Laboratory blanks of sodium sulfate were used to investigate the possibility of contamination. Corn oil was added to the laboratory blanks after June 1996 to better represent the fish matrix. No total PCB results for laboratory blanks were greater than 0.10 μg, and all field sample results exceeded laboratory blank concentrations by a factor of 50, therefore no sample results were qualified for failed blanks or suspected contamination.

Duplicate samples were analyzed to evaluate the precision of analytical results. No field duplicates were collected for the fish matrix, however, laboratory duplicates were analyzed at a frequency of one per extraction batch. No results were flagged for duplicate results that exceeded the MQO of a 40% relative percent difference.

Table 8-9. Summary of Routine Field Sample Flags Applied to Select PCB Congeners and *trans*-Nonachlor in Fish

Analyte	Flags								
	Contamination	Sensitivity	Precision	Bias					Invalid
	FBK	UND	FDL	FMS	FSS	LOB	HIB	FPC	INV
PCB 33	0	62% (490)	NA	NA	9% (70)	0	0	NA	0
PCB 118	0	0.1% (1)	NA	2% (17)	8% (64)	0	0	NA	0
PCB 180	0	0	0	2% (12)	8% (64)	0	0	5% (40)	0
trans-Nonachlor	0	0	0	2% (19)	8% (64)	0	0	20% (158)	0

The number of routine field samples flagged is provided in parentheses. The summary provides only a subset of applied flags and does not represent the full suite of flags applied to the data.

FBK = Failed blank (A related blank had a measurable value above the established QC limit when the blank was analyzed using the same equipment and analytical method. Reported value may be suspect.)
UND = Analyte not detected (Analyte produced no instrument response above noise.)
FDL = Failed laboratory duplicate (A laboratory duplicate associated with this analysis failed the acceptance criteria. Validity of reported value may be compromised.)
FMS = Failed matrix spike (A matrix spike associated with this analysis failed the acceptance criteria. Validity of reported value may be compromised.)
FSS = Failed surrogate (Surrogate recoveries associated with this analysis failed the acceptance criteria. Validity of reported value may be compromised.)
LOB = Likely biased low (Reported value is probably biased low as evidenced by LMS (lab matrix spike) results, SRM (standard reference material) recovery or other internal lab QC data. Reported value is not considered invalid.)
HIB = Likely biased high (Reported value is probably biased high as evidenced by LMS (lab matrix spike) results, SRM (standard reference material) recovery, blank contamination, or other internal lab QC data. Reported value is not considered invalid.)
FPC = Failed performance check (A laboratory performance check sample associated with this analysis failed the acceptance criteria. Validity of reported value may be compromised.)
INV = Invalid (Reported value is deemed invalid by the QC Coordinator.)
NA = Not applicable. The relevant QC sample (e.g., duplicate, matrix spike, performance check) was not prepared or analyzed for this specific analyte.

As discussed in Section 1.5.5, MQOs were defined in terms of six attributes: sensitivity, precision, accuracy, representativeness, completeness, and comparability. GLNPO derived data quality assessments based on a subset of these attributes. For example, analytical precision was estimated as the mean relative percent difference (RPD) between the results for laboratory duplicate pairs. Table 8-10 provides a summary of data quality assessments for several of these attributes for fish data.

System precision could not be estimated for the analysis of fish tissue data because field duplicates were not collected for this matrix. While system precision was not estimated, analytical precision was estimated from the results of laboratory duplicates. Analytical precision for fish PCB and *trans*-nonachlor analysis was very good, with RPDs of only 5.3 and 6.9% for duplicate PCB 180 and *trans*-nonachlor results, respectively. Laboratory duplicates were not analyzed for PCB 33 or PCB 118.

Analytical bias was evaluated by calculating the mean recovery of laboratory matrix spike samples (LMS). Analytical bias was very low, with mean LMS recoveries of 99%, 98% and 90% for PCB 118, PCB 180, and *trans*-nonachlor, respectively. Laboratory matrix spike samples were not analyzed for PCB 33.

Analytical sensitivity was evaluated by calculating the percentage of samples reported below the MDL. No *trans*-nonachlor or PCB 180 results were below the MDL, and only 0.1% of PCB 118 results were below the MDL. For less-chlorinated PCB congeners, such as PCB 33, a majority of sample results were below the MDL. For PCB 33, 81% of 793 samples were reported below the MDL. Results from these samples were not censored and were used as reported in the analysis of fish contamination presented in this report.

Table 8-10. Data Quality Assessment for Select PCB Congeners and *trans*-Nonachlor in Fish Samples

Analyte/Number Field Samples	Parameter	Number of QC samples	Assessment
PCB 33 (793 samples)	Analytical Precision - Mean Lab Duplicate RPD (%), > 5 * MDL	-	NA
	Analytical Bias - Mean Lab Matrix Spike Recovery (%)	-	NA
	Analytical Sensitivity - Samples Reported as < MDL (%)	-	81%
PCB 118 (796 samples)	Analytical Precision - Mean Lab Duplicate RPD (%), > 5 * MDL	-	NA
	Analytical Bias - Mean Lab Matrix Spike Recovery (%)	82 lab matrix spike samples	99%
	Analytical Sensitivity - Samples Reported as < MDL (%)	-	0.1%
PCB 180 (795 samples)	Analytical Precision - Mean Lab Duplicate RPD (%), > 5 * MDL	83 lab duplicate pairs	5.3%
	Analytical Bias - Mean Lab Matrix Spike Recovery (%)	82 lab matrix spike samples	98%
	Analytical Sensitivity - Samples Reported as < MDL (%)	-	0%
trans-Nonachlor (796 samples)	Analytical Precision - Mean Lab Duplicate RPD (%), > 5 * MDL	83 lab duplicate pairs	6.9%
	Analytical Bias - Mean Lab Matrix Spike Recovery (%)	82 lab matrix spike samples	90%
	Analytical Sensitivity - Samples Reported as < MDL (%)	-	0%

RPD = Relative percent difference
MDL = Method detection limit
NA = Not applicable. Laboratory matrix spike samples were not analyzed for PCB 33 and laboratory duplicates were not analyzed for PCB 33 or PCB 118.

8.3 Data Interpretation

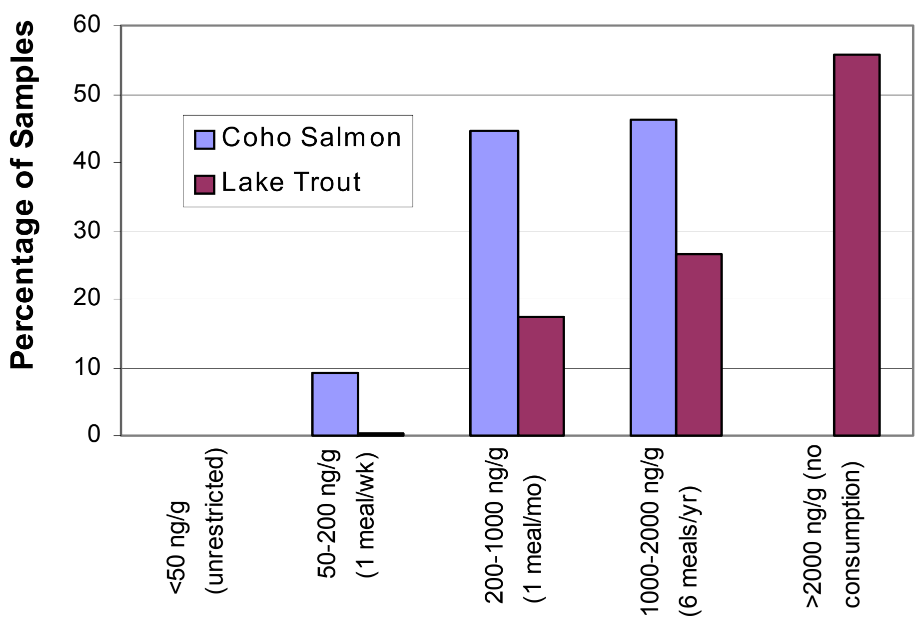
8.3.1 Comparison to Fish Advisory Levels

The Food and Drug Administration has set a tolerance level of 2000 ng/g (2 ppm) for PCBs in fish for human consumption (21 CFR 109.30). Consistent with this tolerance level, the Great Lakes Fish Consumption Advisory Task Force has set a fish advisory category of "no consumption" at PCB levels above 2000 ng/g. Of the Lake Michigan fish analyzed in the LMMB Study, only lake trout contained PCBs above the 2000 ng/g level. In fact, 56% of lake trout samples exceeded this tolerance level, and the mean total PCB concentration for Lake Michigan lake trout was 3000 ng/g (or 3 ppm), which is 50% above the 2000 ng/g tolerance level.

Figure 8-6 shows the percentages of lake trout and coho salmon samples falling into the various Great Lakes fish advisory categories. No coho salmon or lake trout samples fell into the unrestricted consumption category. Coho salmon primarily fell into the 1 meal/mo and 6 meals/yr categories. These categories contained 46% and 44% of coho salmon samples, respectively, with only 9% of coho salmon samples falling into the 1 meal/wk category. Lake trout primarily fell into the no consumption category (56%), with only 0.4%, 17%, and 26% in the 1 meal/wk, 1 meal/mo, and 6 meals/yr categories, respectively.

PCB contamination in fish is positively correlated with fish length, so fish advisories are tied to the size of the fish collected. Based on the regression equation developed from LMMB Study data (Figure 8-3), Lake Michigan lake trout above 575 mm were estimated to exceed the 2000 ng/g FDA tolerance level. Lake trout between 425 and 575 mm would fall into the 6 meals/yr advisory category, and lake trout below 425 mm would generally fall into the 1 meal/mo advisory category. Only one lake trout sample contained less than 200 ng/g (0.2 ppm) total PCBs.

Figure 8-6. Percentage of Lake Michigan Coho Salmon and Lake Trout Samples within each PCB Fish Advisory Category



8.3.2 Comparison to Historical Studies

DeVault *et al.* (1996) and others (Miller *et al.*, 1992; Huestis *et al.*, 1996; Stow *et al.*, 1995) have observed dramatic declines in PCB concentrations in Great Lakes fish since the early 1970s. In Lake Michigan lake trout, mean PCB concentrations declined from 23000 ng/g in 1974 to 2590 ng/g by 1986. Between 1986 and 1992, there was little change in concentrations, with 3490 ng/g observed in 1992. Total PCB concentrations in lake trout measured in the LMMB Study during 1994 and 1995 fit well with this trend. Total PCBs in lake trout analyzed in the LMMB Study averaged 3000 ng/g, which is consistent with the 2590 to 3490 ng/g range of mean total PCB concentrations observed from 1986 to 1992. DeVault *et al.* (1996) hypothesized that the leveling of lake trout PCB concentrations since 1986 (versus continuing decreases) could be due to significant changes in food web structure during that time that has led to increased bioaccumulation. DeVault *et al.* (1996) suggested that the introduction of the predacious cladoceran, *Bythotrephes cederstroemi*, in the early 1980s added an additional trophic level in the pelagic food chain (phytoplankton > zooplankton > *Bythotrephes* > forage fish > lake trout), thus increasing bioaccumulation at trophic levels above this insertion.

Hesselberg *et al.* (1990) measured similar decreases in PCB concentrations in Lake Michigan bloater from 1976 to 1986. Total PCB concentrations in bloater decreased from 5700 ng/g in 1972 to 1640 ng/g in 1986. By 1994 and 1995, total PCB concentrations in bloater were half of the 1986 levels. Total PCB concentrations measured in the LMMB Study averaged 650 ng/g in small bloater chub and 830 ng/g in large bloater chub.

Similar decreases in total PCB concentrations since the early 1970s have been observed for all Lake Michigan fish species (Stow *et al.*, 1995) and for fish species in other Great Lakes. DeVault *et al.* (1996) reported significant decreases in PCB concentrations in lake trout from Lakes Superior, Huron, and Ontario. In Lake Ontario, Huestis *et al.* (1996) observed declines in lake trout PCB levels of 80% between 1977 and 1993, from 9060 ng/g in 1977 to 1720 ng/g in 1993. In contrast, however, Borgmann and Whittle (1992) found no significant temporal trend from 1977 to 1988 in total PCB concentrations in Lake Ontario smelt and sculpin.

trans-Nonachlor concentrations in Lake Michigan fish species were not measured routinely prior to 1986 (DeVault *et al.*, 1996). From 1986 to 1992, *trans*-nonachlor concentrations in Lake Michigan lake trout averaged 220 to 190 ng/g (DeVault *et al.*, 1996). *trans*-Nonachlor concentrations measured in 1994 and 1995 during the LMMB Study were only slightly lower, at 180 ng/g, indicating that like total PCB concentrations, *trans*-nonachlor concentrations in Lake Michigan lake trout have remained relatively constant since the mid 1980s.

8.3.3 Regional Considerations

Among the Great Lakes, concentrations of PCBs in lake trout were highest in Lake Michigan (DeVault *et al.*, 1996). From 1986 to 1992, mean PCB concentrations in Lake Michigan lake trout ranged from 2590 to 3490 ng/g. Mean PCB concentrations ranged from 240 to 450 ng/g in Lake Superior trout, 1170 to 1570 ng/g in Lake Huron trout, 2180 to 2890 ng/g in Lake Ontario trout, and 1320 to 2200 ng/g in Lake Erie walleye (DeVault *et al.*, 1996).

In 1994, Kucklick and Baker (1998) measured PCBs and *trans*-nonachlor in the Lake Superior food web. Total PCB concentrations ranged from 130 to 180 ng/g in bloater, from 42 to 52 ng/g in deepwater sculpin, from 42 to 46 ng/g in slimy sculpin, and from 82 to 160 in lake trout. In Lake Michigan, bloater chub, deepwater sculpin, slimy sculpin, and lake trout measured in the LMMB Study contained up to 5 times, 23 times, 17 times, and 93 times the total PCB concentrations measured in Lake Superior fish species, respectively. *trans*-Nonachlor concentrations in Lake Superior ranged from 18 to 27 ng/g in bloater, from 7.6 to 12 ng/g in deepwater sculpin, from 6.9 to 7.6 ng/g in slimy sculpin, and from 9.7 to 21 ng/g in lake trout. In Lake Michigan, *trans*-nonachlor concentrations in these same species ranged from 4 to 32 times the levels measured in Lake Superior fish.

Total PCB concentrations measured in Lake Michigan fish also were higher than reported levels in fish from numerous other lakes and water bodies. Harding *et al.* (1997) measured total PCB concentrations of 155 ng/g wet-weight in the Gulf of St. Lawrence. In 19 Swedish lakes, Berglund *et al.* (2000) measured a mean total PCB concentration of 55 ng/g dry-weight. In the relatively remote Lake Tahoe, Datta *et al.* (1998) measured 9 to 14 ng/g total PCBs in lake trout. This is up to 1000 times lower than PCB contamination of lake trout in Lake Michigan.

8.3.4 Factors Affecting Contaminant Concentrations

In the LMMB Study, fish contamination levels were primarily affected by species. Within species, contaminant levels were significantly affected by fish length, lipid content, location, and season, but the effect of these factors differed by species. In an evaluation of 20 years of data, Stow (1995) similarly observed that the variability in fish PCB concentrations were explained by year, species, location, length, and length/species effects.

For most species, fish length was strongly correlated with contaminant concentration (Table 8-6). This effect has been commonly reported by other researchers (Stow, 1995; Harding *et al.*, 1997; Huestis *et al.*, 1996), and is likely due to increased contaminant exposure with increasing fish age. Researchers, however, have differed on the importance of fish lipid content in controlling fish contaminant levels. Harding *et al.* (1997) found that the best predictors of PCB contamination in fish were lipid content, followed by size and age. Kucklick and Baker (1998) also determined that lipid content of organisms in the Lake Superior food web explained 81% of the variability in wet-weight total PCB concentrations, with trophic position exerting a smaller influence. The main influence of trophic position on total PCB concentrations was shown to be due to the concurrent increase in lipid content with trophic position.

In contrast, Jackson and Schindler (1996) and Jackson *et al.* (2001) found little evidence of a relationship between PCB concentration and lipid content within species. Stow (1995) also found that after controlling for year, species, location, length, and length/species effects, lipid content showed no relationship with PCB concentrations. In the LMMB Study, the effects of length and lipid content on fish contamination levels varied by species. For some species (lake trout and alewife), lipid content did not significantly affect fish contamination levels. For other species (slimy sculpin), lipid content did significantly affect fish contamination levels and fish length did not. For most species, however, both length and lipid content, or an interaction of the two parameters, significantly affected fish contamination levels.

8.3.5 Bioaccumulation and Trophic Transfer

In the LMMB Study, five forage fish species and two piscivorous fish species were analyzed for contaminant concentrations. Bioaccumulation and biomagnification of PCBs and *trans*-nonachlor within these fish species are discussed here, and bioaccumulation and biomagnification within the entire Lake Michigan food web are discussed in Chapter 9. PCBs and *trans*-nonachlor significantly accumulated in Lake Michigan fish species above concentrations in the water column. Bioaccumulation factors from water to fish ranged from 10^6 to 10^7, depending upon the species and the PCB congener. This is comparable, but slightly higher than, bioaccumulation factors of 10^4 to 10^7 measured by Oliver and Niimi (1988) in Lake Ontario. Bioaccumulation factors also were higher for fish than for plankton (see Chapter 7).

Within the upper pelagic food web (fish), PCBs and *trans*-nonachlor were biomagnified in the trophic transfer from forage fish species to some piscivorous fish. Among the fish species investigated, the piscivorous lake trout accumulated significantly higher levels of PCBs and *trans*-nonachlor than any of the forage fish species. This was true regardless of whether comparisons were made on a wet-weight, dry-weight, or lipid-normalized basis. Biomagnification factors between forage fish species and lake trout were 4.2 for total PCBs and 3.4 for *trans*-nonachlor. The piscivorous coho salmon, however, accumulated significantly higher levels of PCBs and *trans*-nonachlor only when analyzed on a lipid-normalized basis. Biomagnification factors between forage fish and coho salmon (on a dry-weight basis) were below 1 for *trans*-nonachlor and near 1 for total PCBs (1.6), indicating that these contaminants were not significantly biomagnified in the trophic transfer from forage fish to coho salmon.

These findings are consistent with those of other researchers who have calculated higher PCB transfer efficiencies for lake trout than for coho salmon. Using data from 1975 to 1990, Jackson and Schindler (1996) calculated PCB transfer efficiencies of 55% for lake trout and 50% for coho salmon. Using LMMB Study data, Madenjian *et al.* (1998a) similarly estimated that coho salmon from Lake Michigan retained 50% of the PCBs that are contained within their food and lake trout retained 80% of PCBs from food (Madenjian *et al.*, 1998b). Madenjian *et al.* (1998a) suggested that higher transfer efficiencies in lake trout than coho salmon could be due to faster or more efficient gut uptake of PCBs in lake trout than coho salmon. Jackson and Schindler (1996) also suggested that the higher PCB concentrations in lake trout than other salmonids could be due to lower gross assimilation efficiencies for lake trout (~0.17) than for other salmonids (~0.23). (Gross assimilation efficiency is a measure of the rate at which an animal converts food into weight).

In conclusion, PCBs and *trans*-nonachlor were significantly accumulated in Lake Michigan fish. Accumulation was significantly greater in the predacious lake trout than in forage fish species, indicating classical biomagnification. Further evaluation of PCB and *trans*-nonachlor movement and accumulation in the Lake Michigan ecosystem will be provided through the modeling efforts that are the focus of the LMMB Study.